

adverse conditions, it is important that the equipment be designed so that the operators can continue to control it accurately, rapidly, and safely. When accidents can be traced to inaccurate or careless operation of equipment, it occasionally is found that the design of the equipment itself contributed to the accident. Had the controls been so placed that rapid and more accurate judgments and movements could have been made, many of these accidents would not have occurred. Design and production engineers must, therefore, consider not only the physical tolerances and speed that the machine can achieve and the appearance, cost, and ease of production of the apparatus, but also the tasks that the operator is to perform and his abilities and limitations in performing these tasks. Several experimental findings and principles concerning the design of controls are available and should be taken into consideration when designing equipment in order to reduce operator errors and to make speed of operation easier to maintain.⁵⁷

1. Biomechanical Factors Influencing Control Operations

a. *Range of Body Movements.* Basic data on the range of motion of the various parts of the human body and the forces that can be applied in different body positions are indispensable for an understanding of control design. Although it is true that the full range of joint motions or the full force of a particular movement is not usually required in the operation of controls, these data establish

TABLE 7
Amplitude of Movement at Various Joints of Adult Males⁵⁸
(In angular degrees)

Part moved and movement	Side	Mean	S.D.	P.E. est.
Head (relative to trunk)				
Flexion (ventral)		59.8	11.7	.54
Flexion (dorsal)		61.2	26.8	.70
Flexion (lateral)	R	39.4	6.0	.45
"	L	42.9	7.7	
Rotation	R	77.2	16.1	.63
"	L	79.8	12.8	
Arm (at shoulder joint)				
Flexion (forward)	R	179.0	7.2	.45
"	L	179.9	6.3	

⁵⁷ J. H. Ely, R. M. Thomson, and J. Orlansky, "Design of Controls," in *Joint Services Human Engineering Guide to Equipment Design*, Wright-Patterson Air Force Base, Ohio, 1956, Ch. VI.

⁵⁸ A. D. Glanville and G. Kreezer, The maximum amplitude and velocity of joint movements in normal male adults, *Human Biology*, 9, 197-211 (1937).

Table 7 (continued)

Part moved and movement	Side	Mean	S.D.	P.E. est.
Extension (backward)	R	55.2	10.1	.45
"	L	60.0	12.4	
Abduction	R	129.3	11.7	.60
"	L	130.3	11.2	
Internal rotation	R	94.1	22.1	.59
"	L	100.0	16.3	
External rotation	R	82.7	10.0	.55
"	L	83.5	16.2	
Forearm (at elbow joint)				
Flexion	R	138.3	8.5	.47
"	L	144.2	8.9	
Pronation	R	91.1	25.8	.94
"	L	93.0	20.7	
Supination	R	99.4	11.0	.88
"	L	100.6	10.8	
Hand (at wrist joint)				
Flexion (palmar)	R	95.0	10.6	.66
"	L	90.0	9.8	
Extension (dorsal)	R	54.1	15.2	.61
"	L	65.7	12.6	
Abduction (radial flexion)	R	27.1	7.1	.35
"	L	31.1	8.4	
Adduction (ulnar flexion)	R	68.1	8.1	.65
"	L	66.1	8.8	
Thigh (at hip joint)				
Flexion (foreward)	R	97.8	17.0	.63
"	L	105.6	8.3	
Extension (backward)	R	48.4	12.9	.66
"	L	42.4	9.9	
Abduction	R	70.1	17.0	.74
"	L	71.7	14.1	
Internal rotation	R	60.6	15.2	.59
"	L	66.3	13.5	
External rotation	R	37.0	6.6	.60
"	L	30.4	8.3	
Leg (at knee joint)				
Flexion	R	126.6	6.7	.53
"	L	123.7	6.7	
Foot (at ankle joint)				
Flexion (plantar)	R	28.2	7.4	.74
"	L	26.2	8.9	
Extension (dorsal)	R	36.8	6.6	.45
"	L	39.5	8.3	